Agent-Based Virtual Urban Environments for Population Health Applications

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Abstract. Agent-based computational models are gaining traction as a means for modelling the complexities of designing and implementing health interventions in our rapidly-changing society. When such models are integrated with an interactive virtual environment they offer a way to investigate complex conditions including social and environmental determinants, while also facilitating participation and interaction from research users and policy-makers. Here we present a prototype *Agent-Based Virtual Environment* which features an early-stage model of obesity intended to support planners and local authority members in the development of environments that encourage healthy diets and higher physical exertion. We illustrate the construction of the model and its intended role in raising awareness of the role of the built environment in preventing obesity. We also describe future extensions and ways to extend this framework to other areas of concern in public health.

1 Introduction

Increasingly, the potential for computational modelling, particularly agent-based modelling (ABM), has been demonstrated for exploration of complex demographic trends and their impact on population health [3]. For example, ABM work in social care has shown that these approaches can reveal the unexpected consequences of even minor social policy changes when attempting to address the complex interplay of rising demand and falling supply [14].

However, a significant obstacle preventing the more widespread adoption of ABM approaches in public health has been the accessibility of these models for health researchers, policy-makers and local authority stakeholders. Systematic reviews within the public health and epidemiology literature still view ABMs as highly complex and difficult to understand [10]. As a consequence, building productive collaborations using ABM, despite their demonstrable utility for studying complex public health problems resulting from multiple interacting determinants, requires overcoming these methodological and ideological barriers.

Here we present an ABM underpinning an interactive, virtual urban environment based on real-world GIS data (as shown in Figure 1). The modelling framework facilitates direct interaction with an ABM through an intuitive 3D

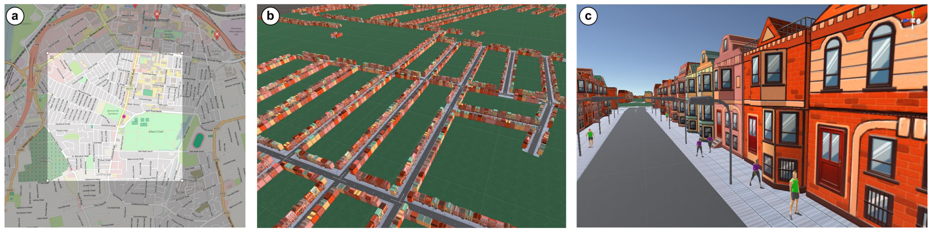

Fig. 1. Generating a 3D urban ABM: (a) OpenStreetMap data is combined with (b) procedural generation of urban landscapes to produce (c) an interactive real-time virtual environment in the Unity3D game engine.

virtual world, which allows the model to be used both as a means of investigating complex public health problems for policy development, and as a learning tool for understanding the phenomena underlying these problems. Users, such as local authorities and town planners, are also able to interact with the virtual world by changing the environment in real time in order to witness the effects of changes on the simulated population. The focus of the system is obesity prevention, where the role of the urban environment is increasingly accepted as an important determinant, and where the complexity of the condition suggest that ABMs are well-suited to modelling the condition. We will demonstrate that this approach allows for the intuitive and engaging presentation of a sophisticated underlying ABM, and that it can ease the process of building the cross-disciplinary bridges that this kind of public health research requires.

2 Background and Related Work

2.1 Agent-based Modelling for Population Health

Complex systems modelling in the form of ABMs can provide useful insights when designing and anticipating the impact of public health interventions. Traditional epidemiological modelling has difficulty capturing the effects of interactions between agents and their environment, known as place effects, in contrast to spatial ABMs in which these interactions are explicitly represented [2]. ABMs can also provide deeper insight into complex health challenges such as health disparities, in which place effects, individual behaviours, and policy changes all play a role in the resulting population health effects [5].

The ability of ABMs to investigate inter-related processes in population health suggests that these methods can make a significant contribution to future research on complex health interventions. Spatially-embedded models featuring interacting agents can incorporate social and environmental effects in a way that statistical methods cannot duplicate. ABMs can also bring some pragmatic advantages, such as the ability to develop simulations of complex social systems even when some population data is hard to collect, or even absent [13].

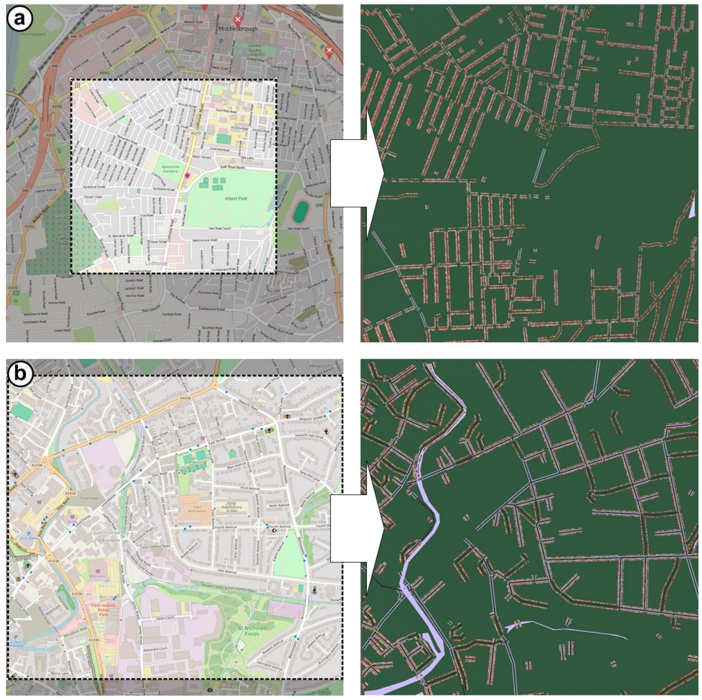

Fig. 2. Selection of the map area to be considered in the simulation from OpenStreetMap and its mapping to the 3D graphical interface: a) Middlesbrough, b) York.

2.2 Modelling Obesity

In England 27% of all adults and 19.8% of all 10-11 year-olds are currently obese [6, 9]. Obesity is associated with a number of serious debilitating and life threatening diseases, resulting in a significant reduction in quality of life and life expectancy. It is a complex condition with over one hundred different determinants, which can be broadly categorised into individual biology and psychology, individual food and physical activity preferences, the food and physical activity environment and the impact of culture and society. Traditionally obesity prevention and treatment has focused on the individual, however there is a need for new longer term approaches that address the environments that promote high energy intake and sedentary behaviours.

The complexity of obesity and its effects suggests that ABMs are well-suited to modelling this condition and developing possible interventions. As a consequence, a number of modellers have developed ABMs of obesity and obesity-related policies, though many of these have focused on only a small subset of the processes involved [8]. Skinner and Foster suggest that while current systems-oriented approaches to the study of childhood obesity are taking better account of its complexity, more ambitious multidisciplinary work needs to take place to better understand its causes and effects [15]. In support of this the recent interest

Fig. 3. (a) Shows a view of the populated simulation at street level, procedurally generated from a library of modular 3D assets. (b) An example of the assets used.

in physical activity monitoring and emergence of a range of affordable activity monitors means that there are readily usable data sets from which underpinning energy expenditure models can be built [12, 1, 18].

The number and variety of models of obesity developed to date suggests that interest in developing ABMs of obesity is clearly substantial. However, while accepting that obesity is both a cause and consequence of numerous inter-related processes, most modelling efforts have attempted to address only a small section of this complex picture. We propose that combining a spatially-embedded model incorporating a real urban environment, with an interactive, three-dimensional visualisation and an underlying ABM can provide a more complete picture of the obesity phenomenon, while also facilitating more productive dialogue between modellers, public health professionals and practitioners, and policy-makers. Illustrative examples of such virtual urban environments are shown in Figure 2.

2.3 The Policy Context in England

We note that in England, the National Planning Policy Framework [4] emphasises that built and natural environments are major determinants of health and well-being, and that the planning system should support strong, vibrant and healthy communities. Certainly local authority planners have control over the "public realm" of the urban environment (e.g. the space between buildings, street network and public spaces), and in the context of weight-management there is a need to concentrate on the impact of decisions taken with regard to the location of public spaces such as public rights of way, squares, parks and public gardens. However, there remain key barriers to this such as: the impact of environmental changes are often longer term, making it difficult to visualise or communicate any potential impact; and natural experiments and interventions in the built environment are hugely costly and at least semi-permanent, so that mistakes are not easily remedied.

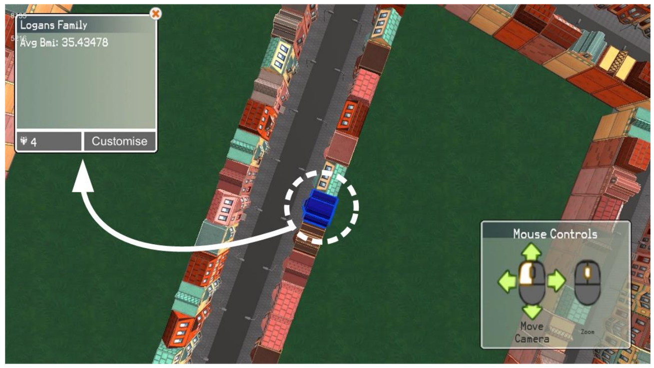

Fig. 4. Example of Interactive Exploration with the System: here a user is shown selecting a specific house/location and investigating the health status of its residents.

Hence one objective of our work is to provide a means to ensure that local authorities are able to include health, well-being and health infrastructure as integral parts of the planning process.

3 System Development

Our motivation was to integrate an ABM approach with an interactive virtual urban environment to provide a new and engaging platform to: raise awareness of the role town planners and other local authority stakeholders have in providing an environment that supports healthy eating and physical activity (food and restaurant outlets, parks, cycling routes, etc); and to help model how individuals might interact with the virtual environment to demonstrate the possible longer-term impact of planning decisions on behaviours that support healthy weight.

3.1 Virtual Environment Development

The primary focus of our work to date has been the development of the interactive urban environment which will allow users to interact with the system and the ABM in order to visually assess the impact of different interventions on the weight status of virtual residents.

We used OpenStreetMap [11] to lay out the virtual urban environments via extraction of city layouts from actual GIS data. For example, we have developed models based on Middlesbrough and York in the UK, as shown in Figure 1. From this city layout the environment is then built up in the Unity3D game engine [17] via procedural generation of the landscape of the virtual environment using a library of modular 3D assets. An example of the street level view of part of such a procedurally generated world is shown in Figure 3.

The current version of the system allows for interactive visualisation of the evolution of the agent population based on a defined scenario (such as the potential positive impact resulting from provision of cycleways in comparison to

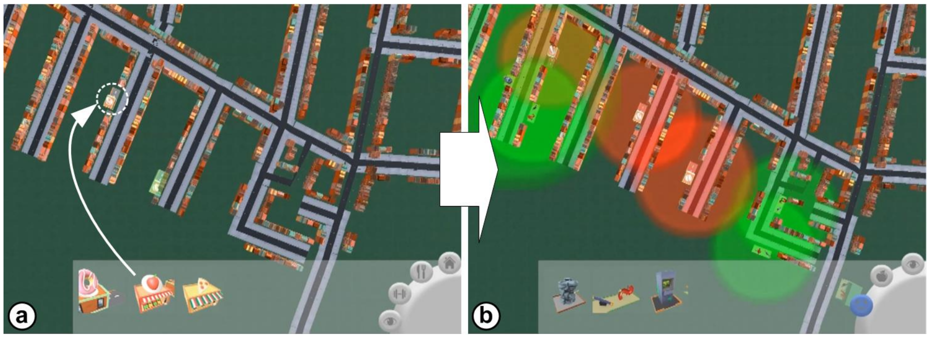

Fig. 5. (a) Urban planning configuration through interactive configuration by adding and removing a selection of outlets (shops, restaurants, parks, etc.) with (b) real-time visualisation of some of the immediate positive and negative impacts on the local areas.

the potential negative effect of placement of fast food restaurants). It also allows for an iterative process of information provision, selection and modification of the town entities, with subsequent generation of a modified simulation based on the new configuration.

In further development our plans are to incorporate virtual agents which will enable exploration of the impact of urban environment and lifestyle changes upon individuals within the target audience.

3.2 Multi-agent Platform Development

For the development of the ABM we are using the GAMA multi-agent platform [16]. We are also adopting an approach similar to that outlined in [7]: starting with characterisation of the environments in which agents live and the BMI dynamics of the simulated agents. As a first step to characterisation of the agent environment we used the same city layout GIS data that was supplied by OpenStreetMap to generate the localised model within the GAMA multi-agent platform. We are currently in the process of building a model of population activities within the GAMA platform. As part of this we are in the process of developing energy balance equations to inform the parameterisation of actions. For example, considering additional energy expended from physical activities such as increased cycle journeys which might result from additional cycle lane provision, the impact of parks, open spaces etc. We also consider the reverse scenario, such as potential impact of the positioning of fast food restaurants.

4 Conclusions and Future Development

In this paper we have summarised our work on the development of a system which features an interactive, virtual urban environment with an underpinning ABM. Models built with this system can be used as a means of investigating

Fig. 6. The figure shows interactive exploration of the urban environment in a Virtual Reality setting. Here the user selects a point in to explore (red pin shown on map).

complex public health problems for policy development, and also as a tool for understanding the phenomena underlying these problem.

In further work we intend to develop the model to include the impact of other local authority departments, such as: trading standards to explore the impact of regulation on healthy food provision and food labelling; and highways departments with responsibility for aspects of the built environment such as street lighting and the impact this may have on street “walkability”.

Another direction is to look at expanding accessibility of the models to the wider community via the development of the programme into a computer game. The aim being both to help raise awareness within the general population and for use as an education aid. This would involve developing the programme into a SimCity-style computer game, with the goal of creating the healthiest city, encouraging people to develop their understanding of the impact of healthy lifestyles outside of the traditional health setting (e.g., promoting healthy lifestyle behaviours through a more engaging medium).

Finally, we also aim to develop new AI representations to support the simulation of intelligent agents with reasoning capabilities related to energy expenditure resulting from their actions.

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